Trimming of photonic components

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Silicon-on-insulator is an ideal material platform for the fabrication of integrated optical components due to the high index contrast, the compatibility with CMOS processes and the transparency for telecom wavelengths. A major drawback of silicon is the low electro-optic coefficient which inhibits the realization of modulators or switches. Liquid crystal can be used as a cladding layer and this enables to tune and modulate optical components in silicon because the effective index of the modes is dependent on the orientation of the liquid crystal in the cladding layer. Limited tunability of ring resonators in silicon up to 1 nm for TE based waveguides was achieved for ring resonators with a bend radius of 6 µm. Recently we have demonstrated much larger tunability of 4.5 nm in TE waveguides and 31 nm in TM based waveguide [1], which means that it is possible to tune over almost the whole telecom C-band which spans from 1530 to 1565 nm. These experimental results are in quite good agreement with results from numerical modeling. The numerical modeling consists of a q-tensor model for the liquid crystal orientation in combination with a full-vectorial mode calculation which incorporates the full anisotropy of the liquid crystal [2].

Deep UV lithography using 193 nm sources is used to fabricate the silicon photonic chips. It has to be noted, however, that the precision requirements for CMOS are much less stringent than they are for photonics. A variation of 10% in the critical dimensions is acceptable for CMOS but dramatic for many photonic devices. As a result, the resonance of the fabricated ring resonators often differs considerably from the designed value, which is unacceptable for many applications. To overcome the fabrication imperfections, the ring resonators have to be trimmed or tuned to the desired resonance wavelength. Tuning requires a constant voltage signal over the LC layer. Trimming on the other hand means that the component is set to its desired resonance wavelength by an irreversible process.

In this work we have deposited a mixture of polymerizable liquid crystal on top of the ring resonators. The ring resonators were then tuned by applying a voltage signal over the liquid crystal overlay. The tuning range that we obtained was 0.75 nm. Then the orientation of the liquid crystal was frozen for a certain voltage applied by illumination with UV light. The polymerization process induces a small redshift of the resonance wavelength, but the final resonance wavelength remains constant, even after removing the voltage. We have applied this trimming process for different voltages and we have measured a trimming range of 0.56 nm [3]. The trimming was demonstrated in a configuration with limited tuning range, but this method will hold also for ring resonators with large tuning range.

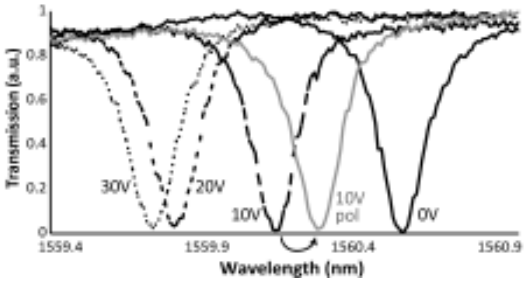

Fig. 1 Transmission of a ring resonator clad with PLC as a function of voltage. Polymerized material results in the gray curve [3].

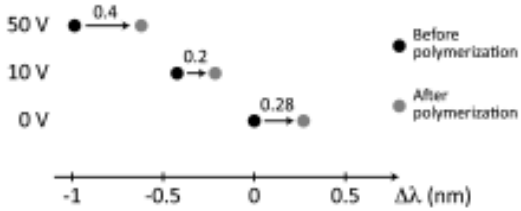

Fig. 2 Shift of the resonance frequency before and after polymerization. The results are obtained for three different test cells [3].

In these results, the photopolymerization induces a quite important shift in the optical properties. This shift is due to two effects. First, there is a refractive index change of the liquid crystal due to the polymerization reaction. Second, the elastic properties of the liquid crystal change, which could results in an important change in the orientation of the liquid crystal close to the waveguide. In order to achieve a well-trimmed component it is vital to either predict this shift or to eliminate the shift. We believe that the shift can be eliminated by applying a stepwise photopolymerization. The UV dose in each step is such that the mixture is not completely polymerized after a single exposure step. After each polymerization step, the voltage over the liquid crystal is adapted. This method was tested by measuring the retardation of a standard planarly aligned liquid crystal cell and the first tests show encouraging results.

Our method of trimming optical components is not limited to silicon-on-insulator waveguides as we believe that this method can be applied to a wide range of optical components ranging from optical retarders, wavelength filters, lenses and microwave components.

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